

Soft X-ray Projection Lithography

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## **Soft X-Ray Projection Lithography**

### **A new program proposal growing out of our long term effort in Advanced X-ray Optics Technologies**

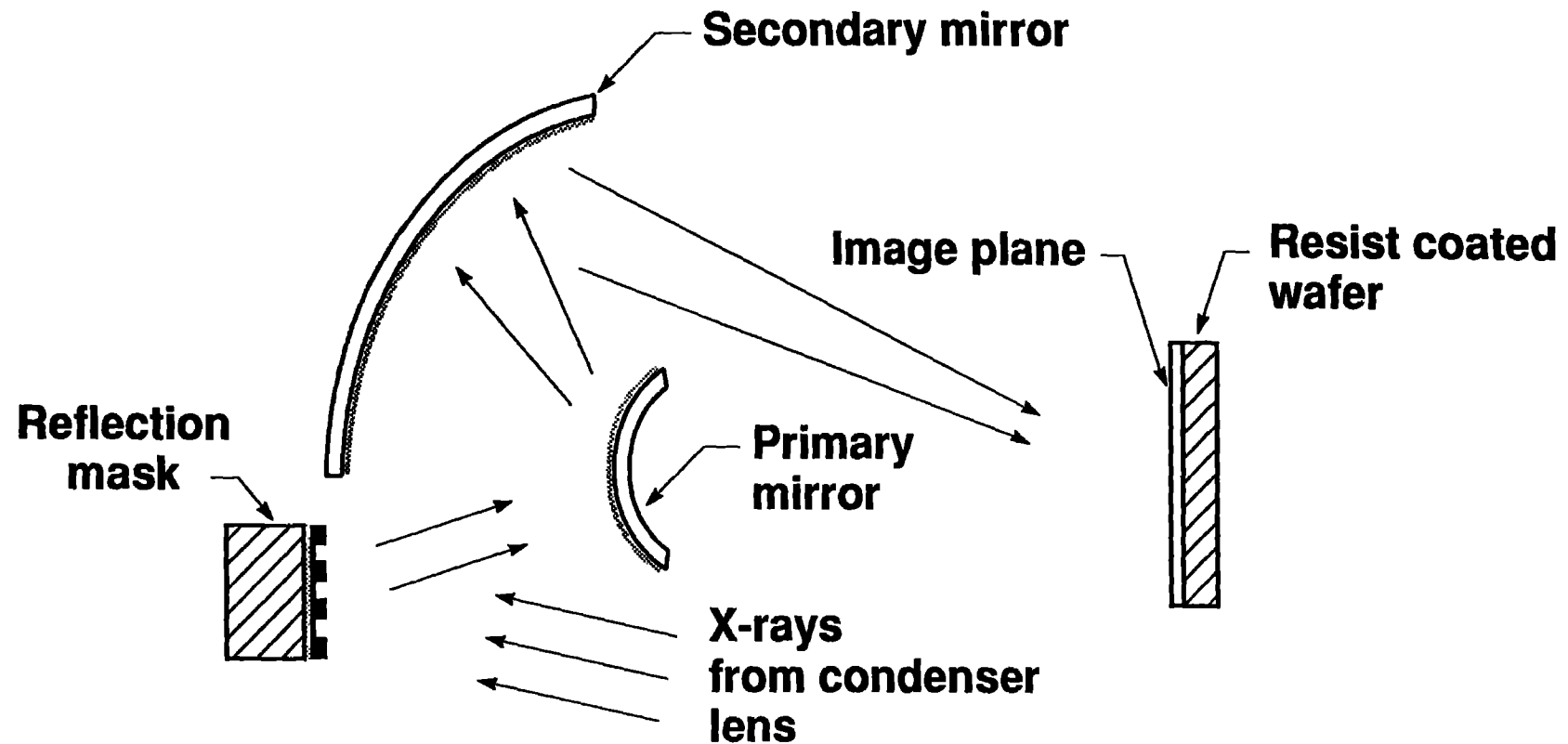
Once a craftsman's art, lithography has become a fundamental enabling technology in the fabrication of modern integrated circuits (I.C.'s) with impact on U.S. economic competitiveness and national security. I.C. fabrication is a significant worldwide industry with sales in 1988 of ~ 35 billion (about 14% of the total electronics industry sales). Worldwide sales of lithographic equipment in 1988 was close to 1 billion \$. In the U.S. over 264 thousand workers are employed in the semiconductor electronics industry. In 1988 Japan widened its lead over the U.S. in worldwide shipments of semiconductors. In a recent, joint-report from the Departments of Energy and Defense, 22 technologies were designated as critical to national security and "the long-term qualitative superiority of U.S. weapons systems." At the very top of this list was: "Microelectronic circuits and their fabrication. Decrease the size and increase the capabilities of computer chips.

The technological choices for the production of these high density integrated circuits of the future represent an area of great controversy in the U.S. lithographic community. For a long while it was presumed that proximity print x-ray lithography would be the technology of choice for the replication of such high density I.C.'s. However, proximity print x-ray lithography has its limitations: it requires high resolution transmission x-ray masks which are expensive, fragile and subject to problems of stability, radiation damage, and limited contrast. In addition, its linewidth resolution is limited to 0.2-0.5  $\mu\text{m}$ , about what "optical" projection lithography is expected to achieve using deep UV excimer lasers. These realities coupled with the billion dollar cost for re-tooling for x-ray lithography have industrial decision-makers understandably anxious.

Our capabilities in soft x-ray optics are allowing us to redefine the dialogue over x-ray lithography by introducing efficient, diffraction limited soft x-ray reduction optics into the discussion. We have recently launched a program to develop soft x-ray projection lithography, which would use sophisticated x-ray reduction optics to project a diffraction limited, demagnified image of an integrated circuit mask onto a semiconductor wafer. Such a system would retain many of the operational conveniences of conventional optical lithography, while taking full advantage of the scaling to a shorter wavelength working radiation. In particular, with the introduction of diffraction limited soft x-ray reduction optics, x-ray lithography would no longer have to be a one-to-one replication process. The need for an expensive, submicron mask technology could be eliminated. In addition, since it is not a proximity print process a reflection x-ray mask could be used which would be more robust and have higher contrast than a transmission x-ray mask. Finally, the ultimate resolution of the projection x-ray lithography would be  $\sim f\#\lambda$  ( $\ll 0.2 \mu\text{m}$ ), providing a competitive lithographic capability well into the 21st century.

A conceptual design with preliminary specification and performance numbers for a soft x-ray lithographic reduction camera operating in a scanning mode is presented below. The system utilizes all spherical optics (multilayer coated) in a monocentric, inverse cassegrain configuration. X-rays from an appropriate (e.g. laser produced plasma or synchrotron beam line) source are concentrated onto an x-ray mask (i.e. master pattern) by a condensing mirror system. The x-ray mask - an I.C. metallization pattern deposited on a multilayer mirror - reflects the incident x-rays into the double-mirror imaging system, which projects a reduced image of the I.C. master pattern onto a resist coated wafer. The prototype reduction camera system is expected to replicate I.C. patterns with linewidths  $< 0.1 \mu\text{m}$ . Lithographic throughput for an industrial system is planned for  $\sim 5 \text{ cm}^2/\text{sec}$  (i.e. roughly two, 6" wafer levels/min.) at  $0.1 \mu\text{m}$  linewidth resolution.

# Soft x-ray reduction optics for scanning system: Design concept



## Soft X-ray Reduction Optics: Preliminary Design Numbers

### Design parameters:

**$\lambda = 130 \text{ \AA}$**   
**5x reduction**  
***f*/6 at wafer**

**Mirror requirements:**

**$R_1 = 3 \text{ cm}$**   
 **$R_2 = 12 \text{ cm}$**   
 **$D < 2.5 \text{ cm}$**   
**Figure error  $< \lambda/12$**   
**RMS roughness  $< \lambda/25$**

### Performance:

**$\delta < 1000 \text{ \AA}$   
over  $2\text{mm}^D$  field at mask  
with  $d\Omega_C \simeq 0.1 \pi \text{ sr.}$  for  $100 \mu\text{m}^D$  source**

Soft x-ray projection lithography is not without its technical challenges. Significant work needs to be done in addressing a variety of scientific, engineering, and design issues before this technology can play a competitive role in industry. However, given our capabilities in multilayer optics, and precision x-ray measurements; our strong collaborative relationships with major industrial players in lithography (IBM, AT&T, General Signal); and the Laboratory's association with a variety of x-ray source technologies (synchrotron, pulse plasma, laser produced plasma, FEL), we are uniquely positioned to successfully address these technical challenges.

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